JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

IMPROVING STEM LITERACY THROUGH PROJECT-BASED GEOSCIENCE LEARNING (PJBGL) MODEL

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Abstract. *The intricacy of real-world challenges in project-based geoscience learning is complex to assess with a STEM approach; hence, research into an effective model is necessary to address current issues in education. Understanding the role of STEM in resolving challenging real-world issues requires integrating STEM literacy that is appropriate for geoscience education. This study examines the effectiveness of the Project-Based Geoscience Learning (PJBGL) model in enhancing STEM literacy. By integrating project-based learning with geoscience, the aim is to create an interactive and immersive learning environment. The study seeks to contribute to knowledge about the effectiveness of this model compared to the conventional model. The aim was to evaluate the PJBGL model's impact on students' literacy, particularly in the geosciences. The study utilized a pretest-posttest control group design with 33 students, 19 in the experimental group and 14 in the control group, collecting STEM literacy data using a test instrument and analyzing the data with the Mann-Whitney test. Effect Size calculation using Cohen's d and increased STEM literacy was tested with the N-Gain formula. The research results show that the PJBGL model is more effective in increasing STEM literacy in geoscience learning than the conventional learning model. This finding holds implications for educators and curriculum developers seeking innovative strategies to cultivate students' STEM literacy.*

Keywords: *geoscience learning, project-based learning, STEM literacy, quasi-experimental design*

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Introduction

The geoscience discipline explores Earth's processes and composition through rock and mineral analysis. The field of geoscience focused on the study of Earth's processes and materials through the analysis of rocks and minerals, faces considerable educational hurdles (Shirazy et al., 2021). In many academic institutions, geoscience is marginalized within the Science Education Subfield, resulting in a need for more specialized courses dedicated to its study (Guhlincozzi & Cisneros, 2022). This issue is further exacerbated by financial constraints related to geoscience practical work, which often leads to its neglect at various educational levels (Akhter et al., 2021; Ayeh & Bleicher, 2021). Consequently, students' understanding of fundamental geoscience concepts could be improved. Students have misconceptions about earthquakes, plate tectonics, weathering, plates floating on the ocean, and earthquakes moving (Koehler & Wild, 2018). Karst landscapes largely lack misconceptions among students (Francek, 2013). Some students confuse hardness with brittleness in geoscience concepts (Giotopoulos et al., 2022). Addressing these challenges is crucial for fostering a deeper appreciation and comprehension of geoscience, ultimately empowering students to engage more meaningfully with the field and contribute to its advancement (Mogk, 2021).

Geoscience education encounters several challenges, such as curriculum misalignment with national standards, insufficient focus on spatial visualization skills, and a need for more emphasis on local geological issues (Brudzinski et al., 2024). Despite its interdisciplinary nature and reliance on direct observation principles, geoscience education faces difficulties due to limited resources, which impede its ability to adequately prepare students for real-world challenges (Barth-Cohen & Braden, 2022). Considering the critical role of geoscience in addressing modern environmental and natural resource issues, improving geoscience literacy is crucial for fostering essential skills in prediction and decision-making (Rodrigues et al., 2023). To address these challenges, it is necessary to bridge the gap between theoretical knowledge and practical application (Wang et al., 2024), thereby enhancing the effectiveness of geoscience education in preparing students for the complexities of the natural world (Vasconcelos & Orion, 2021).

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Geoscience is characterized by a multidisciplinary nature means that the field of geoscience involves the integration of knowledge and methodologies from various scientific disciplines to study the Earth and its processes comprehensively (Mulder & Cordani, 2023). Geoscience, also known as Earth science, is an independent scientific discipline. It encompasses a broad range of sub-disciplines that study the Earth and its processes (Wang et al., 2023). This multidisciplinary approach is crucial in understanding the operational mechanisms and evolutionary patterns of the Earth system. Geoscience integrates principles from physics, chemistry, biology, and mathematics to understand the Earth's structure, composition, and the processes that govern its changes (Power et al., 2023). Furthermore, the field of geophysics, within geoscience, emphasizes the importance of publishing studies that provide a comprehensive overview and synthesis of the current state of knowledge (Florindo et al., 2023; Mogk & Goodwin, 2012; Zheng et al., 2018). Additionally, the relatively young synthetic geographic discipline of geosophy also highlights the integration aspect in science, focusing on the interpenetrating unity of mineral, organic, and human components in geographical features, showcasing the integration of diverse perspectives and methodologies in studying human space (Lynn, 2000; Martyniuk et al., 2023; Pree, 2017). By integrating knowledge and methodologies from various scientific disciplines, geoscientists can gain a more comprehensive understanding of the Earth and address complex challenges facing our planet.

However, there is a recognized need to improve communication and group cooperation skills, which can be addressed through innovative approaches like project-based learning (PBL) (Hussein, 2021). Integrating PBL with STEM education offers a promising solution to these challenges (Fang et al., 2021). Despite these strengths, empirical research specifically focused on STEM literacy development within geoscience education is limited, indicating a critical knowledge gap that needs to be addressed (Maric et al., 2023; O'Connell et al., 2021).

The interconnection between STEM and geoscience is evident in the diverse range of scientific principles, technological tools, engineering applications, and mathematical techniques that are applied to study and understand the Earth system. This interdisciplinary approach is essential for addressing complex challenges related to natural hazards, environmental sustainability, resource management, and climate change mitigation Geoscience is fundamentally a scientific discipline, encompassing the study of the Earth's structure, processes, history, and interactions between it is various components. Technology plays a crucial role in advancing geoscience research, exploration, and monitoring. Remote sensing technologies, such as satellites and drones, provide valuable data for mapping and monitoring Earth's surface features, climate patterns, and environmental changes. Engineering principles are applied in various aspects of geoscience, including geological engineering, geotechnical engineering, and environmental engineering. Mathematics provides the quantitative tools and techniques necessary for analyzing, modeling, and interpreting geospatial data and phenomena.

The specific objective of this study includes evaluating the impact of project-based learning with a STEM approach on student literacy in science, technology, engineering, and mathematics (Baran et al. 2021; Rahmania, 2021). By drawing on existing literature and empirical studies, this research seeks to contribute to the advancement of geoscience education by providing evidence-based insights into effective pedagogical practices that enhance STEM literacy in this field (Andrews et al., 2022; Bao & Koenig, 2019)

Building upon previous research on project-based learning and STEM education, this study integrates these approaches to assess their effectiveness in enhancing STEM literacy within the geoscience domain (Gallay et al., 2021; Wieselmann et al., 2022). By employing assessment techniques such as tests, attitude scales, and performance evaluations, the study seeks to evaluate students' literacy in various STEM domains comprehensively (Zhang et al., 2021). Through empirical observation and analysis, the research aimed to contribute to the advancement of STEM literacy development in geoscience education, thereby addressing the identified knowledge gap (McLaughlin & Bailey, 2023).

Based on the results of a study of geoscience curriculum documents in several countries, it can be said that the approach and structure of the geoscience curriculum vary in various countries. The British, Canadian and Australian curricula were chosen as references because they have good National Curriculums and provide examples of how geoscience can be integrated effectively in overall science subjects. In England, the geoscience curriculum is based on the National Curriculum for Science, which places geoscience material in the subject "Science" which covers four main areas, namely: Earth and Space, Materials, Energy and Earth and Environment (Balmer, 2019; King, 2008; King, 2010). Meanwhile, in Canada, the geoscience curriculum varies by province and territory but generally refers to national curriculum guidelines that cover major scientific disciplines such as Biology, Chemistry, Physics, and Earth and Space Sciences (Metz, 2013; Milford; 2014; Blades, 2019). In Australia, the geoscience curriculum refers to the Australian National Curriculum, where geoscience material is covered in the field of "Science" which consists of three main disciplines: Earth and Space Sciences, Physical Sciences, and Biological Sciences (Maude, 2014;

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Halbert and Salter, 2019; Tomas et al., 2020). Thus, although there are variations in the approach and placement of geoscience material in the curriculum in each country, geoscience education is still recognized as an important part of science education at the international level.

STEM literacy refers to the ability to apply concepts from science, technology, engineering, and mathematics across different contexts. It plays a crucial role in today's education system and beyond, especially with the rapid growth of STEM fields (Kristin et al., 2023). STEM literacy involves applying STEM concepts in diverse settings. It includes problem-solving, knowledge acquisition, communication, decision-making, and integrating science, technology, engineering, and mathematics effectively (Teo et al., 2021; Wannapiroon et al., 2021). Research conducted (by Agussuryani et al., 2022) produced a literature review that STEM literacy can empower HOTS to increase learning activities (Irma & Setiawan, 2023). The study result has shown that applying STEM learning to students' STEM literacy grows pretty well and has a significant impact. According to this study, effective teacher collaboration is necessary for STEM learning to exchange knowledge regarding the challenges and solutions students encounter when working on project assignments (Wang et al., 2020). STEM literacy is very important for success in modern society because it allows individuals to understand and navigate complex issues related to science and technology (Fortus et al., 2022).

Project-Based Learning (PJBL) has been recognized as an effective pedagogical strategy for improving student learning outcomes by fostering deep learning, aligning with 21st-century skills like critical thinking and communication (Dan & Xueyan, 2023). PJBL aims to enhance various skills and core literacy, promoting active learning and development of abilities (Sun, 2023). PJBL promotes direct learning and encourages students to collaborate, think critically, and solve real-world problems (Gabuardi, 2021). Research conducted by Nastiti et al., (2023) produced a literature review that PJBL has a significant positive effect on the ability to think creatively. Zhang & Ma, (2023) produced a literature review that, compared to traditional teaching models, project-based learning significantly improves student learning outcomes and contributes positively to academic achievement, affective attitudes, and thinking skills, especially academic achievement and (Maros et al., 2023), proving higher efficiency in teaching using project-based learning compared to traditional verbal-visual teaching. The study has shown that Project-Based Learning increases student involvement and knowledge retention (Vesikivi et al., 2020).

Geoscience learning focuses on the study of the process and materials of the Earth (Vasconcelos & Orion, 2021). This involves understanding concepts such as geology, meteorology, and oceanography (McNeal & Petcovic, 2020). Research conducted by McLaughlin & Bailey, 2023) produces geospatial research in the future must explore the best way to include spatial skills into the classroom for a long period and must focus on the spatial reasoning process and strategies used by students when problematic spatial phenomena, especially at the elementary and secondary school level (LaDue et al., 2022). They compiled an assessment of the literature from the Geoscience Education Community to the model, highlighting the gaps in the field's current body of knowledge and the potential to promote active geoscience education research. So, it is recommended for future active learning investigations in geosciences by integrating future geoscience education with active learning models. Geoscience education faces challenges such as curriculum mismatch and lack of emphasis on the main skills (Riihimaki & Viskupic, 2020). Increasing geoscience literacy is very important to overcome environmental problems and natural resources (Vasconcelos & Orion, 2021).

The development of PJBGL is very important to increase stem literacy in geoscience education. Geoscience education faces challenges such as marginalization in the sub-field of scientific education and limited resources (Rowan & Dahl, 2023). The PJBGL model integrates project-based learning with a focus on Stem literacy, which aims to increase student understanding and access to authentic research opportunities. Further research is needed to evaluate the effectiveness of the PJBGL model in increasing STEM literacy and overcoming the challenges faced in geoscience education.

Research on the effectiveness of integrating project-based learning with a focus on STEM literacy in geoscience education on student understanding, attitude development, and access to authentic research opportunities is crucial. While project-based geoscience learning aimed at enhancing student literacy has shown continued growth, there needs to be more specialized research focusing on project-based geoscience learning specifically targeting STEM literacy. Despite the widespread availability of information and practices related to PJBL, further research is needed to determine the success rate of PJBL in enhancing STEM literacy, particularly in the context of geosciences. Addressing this challenge requires conducting in-depth research with careful design and adequate control measures. This research has aimed to test the effectiveness. The research question was: Was the PJBGL model more effective in increasing STEM literacy compared to conventional models?

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Research Methodology

General Background

The research quasi-experimental pretest-posttest non-equivalent control group design follows the methodological framework outline (Creswel, 2017). The study procedures encompassed several key steps: initially, administration of STEM literacy pretests to both the experimental and control group, subtractive implementation of the treatment with a focus on stem literacy in the experimental group, and the control group using a conventions model. The effectiveness of the PJGBL model is tested by comparing the average value of the pretest and posttest experimental group and control group. The research was carried out over four meeting sessions at the basic physical laboratory of Palangkaraya State Islamic Institute, Central Borneo, Indonesia, in November-December 2022 with the researcher as the teacher and employee of the PJBGL model.

Population and Sample

The research population consists of Physics Education Study Program students at Palangkaraya State Islamic Institute, Central Borneo, Indonesia as many as 104 students. This research uses purposive sampling, where the sample is selected based on criteria relevant to the research objectives. Purposive sampling was chosen because this method allows researchers to selectively choose samples with characteristics or experiences relevant to the phenomenon under study, thus allowing researchers to obtain rich and in-depth information related to the research topic. Thus, using purposive sampling allows researchers to effectively achieve research goals by focusing on the most relevant samples and can provide significant insights into the phenomenon under study. This study focuses on the quasi-experimental group (19 students) and the control group (14 students) based on the number of students in the classroom. The experimental group undergoes the intervention, while the control group will be used as a comparison to assess the treatment outcome. The sample has expressed willingness to be the subject of the study by being anonymized.

The demographic condition of the respondents in this study were 4th-semester Physics Education Study Program students aged 18-19 years. Respondents also have the same socio-cultural background, namely students from the Central Kalimantan area. In this study, matching was carried out between groups that received treatment and groups that were comparable in characteristics. The characteristics that are equalized are age range, grade level, and socio-cultural background. These similarly paired groups are then compared, with one being the experimental group and the other being the control group. The process of determining the experimental and control groups was carried out by matching respondents based on demographic variables such as age range and semester level. The experimental and control groups were selected by randomly selecting classes that were equivalent in terms of demographics.

Procedures

Experimental groups

In quasi-experimental research with a pretest-posttest design and a non-equivalent control group, the selection of experimental classes must be done carefully. One approach that can be used is the PJBGL Model. The class receiving treatment or intervention with the PJBGL Model is selected as the experimental group. The selection of the experimental class must consider certain characteristics, such as learning ability and motivation, to be comparable to the control group (Yin et al., 2021). Thus, differences in results between the two groups can be attributed more definitively to the treatment or intervention provided rather than to differences in initial characteristics between the groups (Balkin & Lenz, 2021). This step is important to reduce bias and increase the study's internal validity.

In general, the syntax of a learning model consists of a structure composed of the main elements and phases of the model and how they are put together (Joyce et al., 2016). The PJBGL model is a model development of the PJBL syntax (Patton, 2012b) based on Geoscience Learning (Mogk & Goodwin, 2012). The following is the syntax of the PJBGL Model syntax: (1) Orientation Phase Fundamental Question. By connecting the body and mind through interactions with the natural and social surroundings of the geoscience subject, students can choose/determine the theme/topic of the project based on the material/task supplied by the educator; (2) Planning Phase. By following the guidelines for implementing project tasks, choosing activities that can support project tasks, integrating multiple options for completing project tasks, planning sources of materials and tools that can help the completion

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

of project tasks, and fostering group cooperation, students can organize the steps of project completion activities from start to finish; (3) Exploration Phase. With the lecturer's help, students can create a timeline for carrying out their learner's project. The timeline should take into account the activities that have been planned and the amount of time that each step of the project requires to be completed. Additionally, students can locate reading materials to supplement the project as needed and use maps, sketches, and diagrams to illustrate, validate, rationalize, and externalize their understanding of the earth and geosciences. Once students know the assumptions, boundaries, and uncertainties inherent in the geoscience profession, they can perform their field practicum according to norms, language and discourse, tool selection and use, ethics, and values; (4) Monitoring Phase. Students can carry out project activities from beginning to end by implementing the project design created and overseen by the instructor; (5) Evaluation Phase. Students can create reports and presentations of project outcomes in the form of products, such as literary works, artistic creations, or technological works/workshops that are displayed as educational product displays to other students, teachers, and members of the community. Students have the option to consider their actions as well as the outcomes of their project tasks. Students can share their experiences throughout the evaluation stage through discussion to increase performance while completing the project task. At this point, comments regarding the procedure and final goods are also made.

The exploration syntax of the PJBGL model requires students to find or explore with the aim of discovery. Students design prototype technology products for geoscience material, fostering intellectual development through problem-solving (Hoermann et al., 2022). The monitoring syntax involves routine data collection and progress measurement, focusing on process and results through discussion. Students create scientific posters to solve geoscience problems, enhancing their ability to understand phenomena from various perspectives and generate unique ideas.

In designing and implementing project-based geoscience learning activities with a focus on rock material, increasing the integration of STEM literacy in project-based geoscience learning in each learning syntax facilitates growing STEM literacy. First, in the field of geoscience education, exposure to the latest technology plays an important role in improving students' understanding and application of geological concepts (Hoyer & Hastie, 2023). in the technological aspect, students are not only introduced but actively engaged in the latest and newest existence in geological mapping and rock analysis data. This hands-on experience serves to bridge theoretical knowledge on practical skills, ensuring that students are equipped with both real-world challenges in the field of geosciences (Harrell et al., 2023).

Second, in addition, rock data analysis has been revolutionized by the emergence of advanced technology (He et al., 2021). One example of what students do is by analyzing the density and porosity of rocks in Bukit Banama. Students use several tools, one of which is the Carbolite Thermo Scientific Furnace used in various laboratory applications for the process of heating, drying, and burning materials with accurate and stable temperature control. The material used is rock from Bukit Banama. By knowing the density and porosity of the rock, we can gain detailed insight into the mineral composition and texture of the rock (C. Zhao et al., 2021). Density is the mass per unit volume, while porosity is the ratio of pore volume to total volume (Fu et al., 2021). This information is important in evaluating the physical and mechanical properties of rocks, as well as in understanding rock formation and transformation processes (Rashid et al., 2022). The density of a rock is affected by the type of minerals and their amount, while porosity indicates how much pore space or cracks there are in the rock (Iranfar et al., 2023). Thus, knowledge of rock density and porosity is the basis for further analysis of the characteristics of the rock and its geological environment (Eyinla et al., 2020). These techniques, when coupled with specialized software, allow the quantification and interpretation of rock properties with unprecedented precision (Wang et al., 2024). This method is important for obtaining detailed information about the structure and composition of rocks, as well as understanding their physical and mechanical properties in more depth (Kahraman et al., 2024).

Third, in the engineering aspect, students will be involved in designing the project itself and encouraged to develop exploration and analysis methods suitable for the project objectives while considering environmental factors and resource availability (Beneroso & Robinson, 2022). This process offers real-world experience in applying engineering concepts within a geoscience framework, fostering problem-solving skills and creativity (Chen, 2021). Additionally, in the technical aspect, students will design the project, developing exploration and analysis methods tailored to the project's objectives, considering factors such as environmental impact and resource availability (de Rezende et al., 2022). The integration of advanced technology in geoscience education is crucial in preparing students for modern geological practice (Chen, 2021). By familiarizing them with the latest tools and techniques in geological mapping and rock data analysis, educators can empower students to become proficient geoscientists capable of addressing contemporary challenges in the field (Laporte, 2022). The implementation of

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

a Geoscience Project provides students with the opportunity to apply learned concepts and methods in a practical setting, enhancing their analysis, research, and presentation skills within a geoscience context (Hoyer & Hastie, 2023).

Fourth, the engagement with geoscience software and hardware provides students with an opportunity to develop critical skills in data manipulation and visualization, which are essential for interpreting complex geological phenomena and communicating findings effectively (de Castro et al., 2024). By immersing students in the use of such technologies, educators can cultivate a cohort of geoscientists proficient not only in technical aspects but also in communication (Al-Ismaily et al., 2023; Lillico, 2022). Additionally, in the mathematical aspect, students will actively engage in quantitative analysis of geological data. They will apply mathematical concepts to interpret data, take measurements on a geological scale, and create mathematical models or representations of rock structures (Qiu et al., 2023; Shcherbakov et al., 2021). This involvement in mathematical skills will enhance students' understanding of rocks as entities that can be described mathematically.

Project-based geoscience learning activities focused on rocks can significantly enhance students' comprehension and retention of geological concepts. These activities involve hands-on exploration and experimentation, allowing students to engage actively with the subject matter and fostering a deeper understanding of geological processes. Furthermore, encouraging students to collaborate and communicate effectively promotes the development of essential skills such as teamwork, problem-solving, and critical thinking. Overall, project-based geoscience learning activities about rocks deepen students' understanding of the material and develop multidisciplinary skills crucial for a career in the geoscience field. By engaging students in hands-on, collaborative projects, educators can cultivate a new generation of geoscientists who are knowledgeable and skilled in applying their knowledge creatively and scientifically.

Control groups

To maintain the validity of quasi-experimental research with a pretest-posttest design and a non-equivalent control group, selecting a control group requires careful consideration. The class that was used as the control group did not receive any additional treatment and still underwent conventional learning as usual (Hamilton et al., 2021). This class served as a comparison group to evaluate the effectiveness of the intervention given to the experimental group. It was important to select a control group comparable to the experimental group regarding relevant baseline characteristics, such as learning ability and motivation. This way, differences in outcomes between the two groups can be more accurately attributed to the treatment or intervention provided rather than to differences in baseline characteristics between the two groups (Zhao et al., 2021). This step is important to reduce bias and increase the study's internal validity.

In an experimental study to assess the physical properties of rocks, two groups of subjects, an experimental group, and a control group, were assigned. Both groups were given the same material on the concepts of porosity and density of rocks. Porosity refers to the volume fraction of cavities or empty spaces in a rock that can be filled by fluid, while density refers to the mass per unit volume of rock. Porosity and density measurements are made using standardized methods and instruments, such as digital image analysis or direct mass and volume measurements. The purpose of providing the same material to both groups was to ensure that their initial understanding of the concepts was equivalent before different treatments or interventions were conducted in the experimental group. The time spent on these topics for the experimental and control groups was the same duration, namely four meetings with 150 minutes per meeting. In the experimental group, the lesson was structured using the PJBGL syntax, while the control group used a conventional model with a demonstration syntax.

Data Collection Instrument

With ten items designed to evaluate students' STEM literacy, this study tool comprises questions focused on various aspects of STEM literacy. Covering 10 distinct STEM literacy metrics, these questions are designed to gauge students' proficiency in STEM subjects. STEM literacy refers to individuals' capacity to comprehend and apply the principles of science, technology, engineering, and mathematics to address issues, make choices, and engage in situations related to STEM. The assessment tool used in this study aims to evaluate the literacy level of participants through inquiries covering key areas of science, technology, engineering, and mathematics. The literacy measure employed is presented in Table 1.

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 1
Grid of STEM Literacy Instrument Based on Geoscience Project

Discipline	Indicator
Science	Given a picture of rock magnetism, students can explain the problem based on the picture correctly.
	Presented data about the results of rock observations, students can evaluate problems based on these data appropriately.
	Presented pictures about the results of observations about geoscience; students can evaluate problems based on the data correctly.
	Given a picture of technological principles, students can explain problems based on these technological principles appropriately.
Technology	Given the results of data processing about rock magnetism, students can analyze the use of technology appropriately.
	Given a narrative about rock magnetism, students can formulate problems based on the narrative correctly.
Engineering	Given a problem regarding practicum tools, students can develop solutions by using these tools properly.
	Given a mathematical problem of rock magnetism, students can formulate the problem mathematically correctly.
Mathematics	Presented image data about rock stratigraphy; students can interpret data based on this data correctly.
	Given a mathematical problem of rock magnetism, students can interpret the solution accompanied by empirical evidence using mathematics about rock magnetism correctly.

Table 1 presents the results of a comprehensive synthesis of existing literature or expert evaluations, providing a detailed breakdown of the key aspects of STEM literacy that were identified as crucial for assessment in this study. The table serves as a valuable reference for understanding the specific topics and concepts within science, technology, engineering, and mathematics that were considered essential for measuring literacy levels among participants.

The content validity test obtained an average Aiken coefficient value of .99, falling within the good category. The construct validity analysis based on the results of the confirmatory factor analysis revealed a p-value of .15, GFI of .95, AGFI of .92, and RMSEA of .036. The squared error is approximately .036, which is less than .08, and the chi-square test yielded a value of 1.19, which is less than 2, with an appropriate index of .95, exceeding the threshold of .90. This model, selected from field data, can be applied to various measurements. The Composite Reliability value of .7 falls within the reliable category. As the developed instrument has met the validity and reliability requirements, it can be utilized by geoscience educators in higher education to measure the STEM literacy of physics students.

The content validity test obtained an average of Aiken coefficient value .99 in a good category. The construct validity analysis based on the results of the confirmatory factor analysis, it was found that *p* .15, GFI .95, AGFI .92, and RMSEA .036. The squared error is approximately 0.036; 0.08, and the chi-square test is 1.19; 2, with an appropriate index of .95; .90. This is a model selected from field data that can be used for many different measurements. The Composite reliability value of 0.7 is in the reliable category. Since the developed instrument has met the validity and reliability requirements, geoscience teachers in higher education can use it to measure the STEM literacy of physics students.

Throughout the application process, this STEM literacy tool has undergone multiple examinations, including testing, measurement, validation, and qualitative analysis. As previously said, experts examine and conduct experiments to test the model. The results of the expert model evaluation according to the preliminary design review, the proposed model appropriately emphasizes STEM literacy. An instrument is considered valid if the expert feels it can measure the intended variables (Cantabrana et al., 2019; Garg et al., 2021; Howells et al., 2020). The study results indicate that out of the 10 items created, they possess a loading factor value. The metrics employed are RMSEA and (GFI) (Lukman et al., 2021). The GFI standards have been met as the produced value falls within the specified range. This indicates that the model acquired is suitable, suggesting that the instrument's design is sound and may be used to assess the distribution of this measurement model.

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Analysis

The Levene test was utilized to examine the homogeneity of variances. The data is deemed homogeneous if the p-value is greater than or equal to .05 ($p \geq .05$). The outcomes of these preliminary analysis tests are presented in Table 2.

Table 2
Analysis Prerequisite Test

Testing	Kind Test	Significance	Decision
Homogeneity	Levene	STEM Literacy: .141	Homogeneous

The post-test and pre-test data were meticulously analyzed using descriptive and inferential statistical methods. Descriptive analysis calculates the mean, median, mode, range, variance, and standard deviation. These metrics provide a comprehensive summary of the data distribution and central tendency. Inferential analysis, on the other hand, was conducted using the Mann-Whitney test. This statistical test was employed to determine if significant differences existed between the effects of the Project Geoscience learning model and the conventional model on enhancing student STEM literacy. Effect Size calculation using Cohen's d and the level of increase in STEM literacy was tested with the N-Gain formula. This approach allowed for a rigorous evaluation of the effectiveness of the different teaching models in promoting STEM literacy among students.

Research Results

The descriptive statistical analysis of pre-test data on STEM literacy is encapsulated in Table 3, elucidating the baseline proficiency levels before the intervention. Complementing this initial assessment, Table 3 delineates the descriptive statistics derived from the post-test data, furnishing insights into the participants' STEM literacy after the implemented measures. Descriptive statistical results Pre-test data literacy STEM is presented in Table 3.

Table 3
Descriptive Statistical of Pre-Test and Post-Test STEM Literacy

Group	*N*	Pre-Test		Post-Test		N-Gain
		$\bar{X}$	*SD*	$\bar{X}$	*SD*	
Experiment	19	41.21	1.513	88.21	0.819	0,79
Control	14	40.29	1.619	69.29	1.563	

Table 3 shows a summary of descriptive statistical analysis results, indicating that the average posttest literacy STEM from the implementation of the experimental class PJGBL was higher than the average STEM literacy from the control class. The standard deviation of STEM literacy in PJGBL learning was smaller than the standard deviation of the control class. This indicated that the data tended to be convergent towards the mean.

The Mann-Whitney test was also used to determine the effect of PJGBL on STEM literacy. The following are the results of hypothesis testing using the Mann-Whitney Test analysis which are shown in Table 4.

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 4
Test Statistics Uji Mann-Whitney

	STEM Literacy
Mann-Whitney	19.500
Wilcoxon W	124.500
Z	-4.147
Asymp. Sig. (2-tailed)	.0001

Table 4 shows the Test Statistics output in the Mann-Whitney test. It is known that the Asymp. Sig. (2-tailed) of < .001 is smaller than the probability value of .05. Therefore, as is the basis for making the Mann-Whitney test decision, it can be concluded that H_a is accepted. Thus, it can be said that there is a significant difference in the median between the experimental and control classes. This indicates that using PJBGL in the classroom has a more significant impact on raising student literacy. A coefficient of 3.81 in the high category was found by applying Cohen's D method to calculate the Effect Size. This demonstrates how well the PJBGL Model improves STEM literacy—the outcome of the N-Gain analysis is the following analysis. Following computation, an N-Gain value of .79 in the high category was achieved. Based on these values, the PJBGL strategy can raise STEM literacy with a very high category.

Discussion

The research results revealed a significant difference in increasing STEM literacy between the experimental and control classes. The experimental class, which underwent treatment with the PJBGL model, showed a much greater increase in STEM literacy than the control class which applied the conventional learning model. These findings highlight the significant potential of the PJBGL model in increasing STEM literacy. In this context, the differences in results between the two groups suggest that learning designs that focus on projects and STEM literacy simultaneously can provide greater benefits than conventional learning methods that do not explicitly emphasize aspects of STEM literacy.

The research findings from various studies on STEM-integrated PjBL models underscore the substantial potential of this approach in enhancing STEM literacy (Nurhayati et al., 2023; Nuraini, 2023). A comparison between experimental and control groups reveals that learning models combining project-based learning with a focus on STEM literacy yield more significant benefits than traditional methods that do not explicitly emphasize STEM literacy aspects (Hayuana et al., 2023). These results indicate that integrating projects and STEM literacy in educational designs can lead to improved outcomes in terms of students' motivation, scientific literacy skills, and overall learning achievements (Muskania et al., 2023). Therefore, the evidence suggests that educational strategies emphasizing both projects and STEM literacy concurrently offer a more effective approach to enhancing students' understanding and proficiency in STEM literacy compared to the conventional learning model.

Research shows that there is an increase in STEM literacy in classes that use PJBGL. This is because each stage or syntax in the PJBGL model is designed to specifically grow students' STEM literacy abilities. For example, project activities in PJBGL not only teach geoscience concepts, but also engage them in problem-solving, critical thinking, and communicating effectively in a STEM context. As a result, students who engage in PJBGL-based learning tend to develop their STEM literacy skills better than students who learn through conventional approaches. PJBGL offers an immersive and comprehensive learning environment where students can gain a deeper understanding of STEM literacy.

Based on the research findings from various studies, it is evident that Project-based Learning with a STEM focus can significantly enhance students' literacy skills in these areas. Studies have shown that interactive STEM learning is particularly effective in improving mathematical literacy skills among elementary school students in urban areas (Susanta et al., 2023). Additionally, the use of STEM-integrated Physics Digital Teaching Material (PDTM) has been found to positively impact students' conceptual understanding and new literacy skills, including data, technology, and human literacy (Susanta et al., 2023). Furthermore, Design-Based Learning (DBL) approaches have been shown to improve content learning and foster STEM identity among students, with different DBL methods yielding varying outcomes in terms of STEM literacy development (Asrizal et al., 2023). These findings

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

collectively support the idea that PJBGL-based learning can indeed facilitate the development of students' STEM literacy skills more effectively than the conventional model.

The PJBGL model, which integrates project-based learning with a focus on STEM literacy in geosciences, has shown the ability to increase STEM literacy. Modification of the PJBGL syntax involves students in orienting to science and technology development in geosciences, integrating this with learning geosciences in the field with a STEM literacy approach. The modified syntax, named PJBGL with STEM literacy, consists of five phases: Orientation, Planning, Exploration, Monitoring, and Evaluation. The orientation phase facilitates students in selecting project themes based on given tasks, integrating mind-body interaction in the natural and social environment to build knowledge and attitudes.

The PJBGL model is more effective than the conventional model commonly applied previously to increase STEM literacy. This is because the syntax in the learning model has the advantage of facilitating an increase in STEM literacy indicators (Lina & Amidi, 2023; Muzana et al., 2021). Data collection syntax, solution design, and communication are the strengths of this model in increasing the ability of STEM literacy (Muzana et al., 2021; Purwaningsih et al., 2020). Various ways can be done to increase STEM literacy, namely learning and assessment (Hikmawati et al., 2020; Tati et al., 2017; Xu et al., 2019). Ideally, the evaluation activities conducted should align with the instructional method employed. The literacy evaluation of STEM will be suitable if the learning method utilized already includes that skill. Nevertheless, if the education conducted does not promote these skills, it does not imply that STEM literacy cannot be achieved.

In the PJBGL teaching model, students are helped to solve problems through activity-based learning, discovery centered on students (Jackson et al., 2021; McDonald, 2016; Nurlaely et al., 2017). The PJBGL learning model encourages students' science attitudes and encourages them to actively participate in the search for ideas and link their experiences with the material being studied. Therefore, Literacy STEM combines science and mathematics lessons with elements of technology and engineering in geosciences to attract students. This integration is appropriate because students receive the initial exposure to technology and techniques when studying geoscience material. This is also shown by the PJBGL model and Literacy STEM, which correlate, namely (1) Contextual relevance: The PJBGL model allows students to learn about geosciences in the context of real situations or concrete projects. Students can study natural phenomena, environmental problems, or other geoscience challenges that are relevant to everyday life. (2) Practical Experience: The PJBGL model allows students to take part in geoscience projects that involve field observation, data analysis, and real geoscience problem-solving. This helps students understand geoscience concepts more deeply. (3) Active involvement: In the PJBGL model, students are actively involved in the planning, implementation, and evaluation of their projects. Students play an important role in learning, which increases motivation and understanding. (4) Collaboration and communication: Projects in the PJBGL model often involve teamwork and collaboration, which are important skills in the fields of geosciences and STEM in general.

Additional research refers to empirical investigations that provide a more detailed description of the processes involved in construction or improvement. This study can clarify the procedure and formation of the models created. Firstly, this method enables the establishment to create a fresh framework with a suitable level of clarity to concentrate on several issues. Furthermore, users, specifically instructors and students, may readily understand the model outcomes. This study presents a model that has been demonstrated to be valid and can be utilized by instructors who are closely connected to the context, material, and students.

The PJBGL learning model received a very positive response from the lecturer and students because the range of values of students and educators was in the third range of quartile and maximum grades. This PJBGL learning model meets the practical criteria of a learning model, namely (1) the model can be applied in learning geoscience material; (2) the time, energy, and cost of using affordable models; and (3) the syntax of the PJBGL learning model is by this learning objective, namely, to increase STEM literacy.

This PJGBL model further encouraged and provided opportunities for students to do foreign tasks and was able to hone their ability to explore knowledge with STEM literacy compared to educators who only provided routine tasks (Mulyani, 2019; Roshayanti et al., 2022; Satria, 2016). The importance of the role of lecturers in facilitating the literacy of students' STEM must also be in line with the literacy of the lecturer STEM itself. Educators are role models in exploring information in science (Cayirdag, 2017; Hines et al., 2019; Lukman et al., 2021). Enhancing learning patterns in various areas impacts educators' mindsets and improves learning patterns in educational institutions, as well as the support from families and the surrounding environment. Educators should also be able to understand and implement appropriate learning models for their students.

https://doi.org/10.33225/jbse/24.23.694

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Although the PJGBL model has several advantages, this research certainly has limitations, such as project models developed too specifically with geoscience material characteristics. Therefore, it is recommended for further researchers to develop a project learning model that is more flexible to other materials.

One limitation of this study is the reliance on one statistical analysis tool, SPSS. While SPSS is powerful and widely used, its limitations in handling complex analyses may affect the depth of the findings. The use of Cohen's d-effect size test may provide a quantitative measure of treatment effect but may need to capture the nuances of treatment effectiveness fully. Future research could explore alternative statistical analysis tools and effect sizes for a more comprehensive analysis of treatment impact to overcome these limitations.

This research demonstrates the effectiveness of the PJBGL model in enhancing students' STEM literacy fields. By comparing an experimental group utilizing PJBGL with a control group employing conventional methods, the study underscores the substantial advantage of PJBGL in promoting STEM literacy, corroborating prior research on the potential of PJBGL-based approaches to improve students' STEM literacy competencies. Moreover, insights from various studies emphasize the benefits of integrating projects and STEM literacy into educational designs, as such approaches have been shown to positively impact students' motivation, scientific literacy abilities, and overall academic achievements. Additionally, research suggests that interactive STEM learning, the utilization of STEM-integrated teaching materials, and Design-Based Learning approaches can significantly contribute to the enhancement of students' STEM literacy proficiency.

Conclusions and Implications

After conducting comprehensive data analysis and comprehensive interpretation of results, the findings of this study provide empirical evidence that convinced that: Based on the results of the discussion, it can be concluded that the PJBGL model is more effective in increasing STEM literacy than conventional learning model. This study presents a model that has been demonstrated to be valid and can be utilized by instructors who are closely connected to the context, material, and students. Research shows that the experimental class that received treatment with the PJBGL model experienced a significant increase in STEM literacy compared to the control class that applied the conventional learning model. These findings are supported by previous research which also highlights the great potential of the PJBGL approach in improving students' STEM literacy skills. The integration of projects and STEM literacy in the design of the PJBGL model has been proven to provide greater benefits than conventional learning methods that do not explicitly emphasize aspects of STEM literacy. These conclusions demonstrate the relevance and importance of innovative approaches in education to prepare students to face the demands of a world increasingly focused on STEM. This finding holds implications for educators and curriculum developers seeking innovative strategies to cultivate students' literacy skills in STEM disciplines, ultimately preparing them for success in an increasingly STEM-centered world.

Acknowledgments

To achieve scientific excellence and develop this article, sincere thanks are due to various individuals and institutions whose contributions were crucial in realizing it. Thanks are due to the entire writing team for their tireless cooperation in forming ideas, collecting data, and formulating findings, which were crucial to the success of this article as well as to each contributor.

Declaration of Interest

The authors declare no competing interest.

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Received: *April 29, 2024* Revised: *June 16, 2024* Accepted: *August 08, 2024*

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Cite as: Nastiti, L. R., Sunarno, W., Sukarmin, S., Saputro, S., & Baehaqi, L. (2024). Improving STEM literacy through project-based geoscience learning (PJBGL) model. *Journal of Baltic Science Education*, *23*(4), 694–709. https://doi.org/10.33225/jbse/24.23.694

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